NEW LIGHT ON THE STRUCTURE OF MATTER.

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NEW LIGHT ON THE STRUCTURE OF MATTER.

THE problem of the structure of matter is by no means modern. The conception of atoms dates back to ancient classical days. That matter consisted of ultimate discrete particles was the view advanced by Democritus and later expounded by Epicurus and his followers. Again, during the unscientific Middle Ages, discussions as to whether matter were a *plenum* or of a grained structure were common among the Schoolmen. But old as the problem is, it is to comparatively modern scientists that we owe all the real advances which have been made in this field of enquiry. At the beginning of the nineteenth century Dalton advanced his atomic theory of matter and since that time much has been done to place this theory on a firm basis. Concerning the structure of the atom itself, however, little was known until within the last twenty-five years. The position in 1875 may be summed up in the following words of J. Clerk Maxwell: "The formation of a molecule is therefore an event not belonging to that order of nature under which we live. It is an operation of a kind which is not, so far as we are aware, going on on earth or in the sun or the stars, either now or since these bodies began to be formed. . . . *Each (atom) is physically independent of all the others.*" In these words we have the conception of the greatest physicist of his time. At this time, it is true, the atom was not considered to be a simple body. Indeed, in the early eighties, we find another famous physicist, from a consideration of spectroscopic work, remarking that "compared with a grand piano ,the atom of iron must be a very complex structure." But the absolute independence of atoms of different substances, their absolute constancy and unchangeability were universally accepted.

During the last quarter of a century, since 1895, if one were asked to assign a definite year, little short of a revolution has taken place in the physicist's concept of the atom. No longer does each atom reign supreme in its own domain, no longer does an atom of silver refuse to have anything in com-

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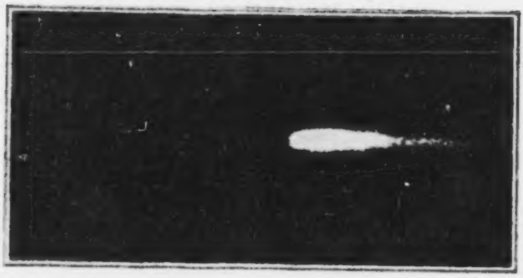


Figure 4.

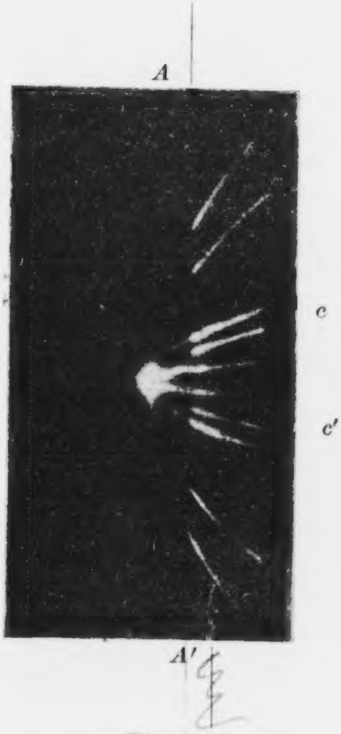
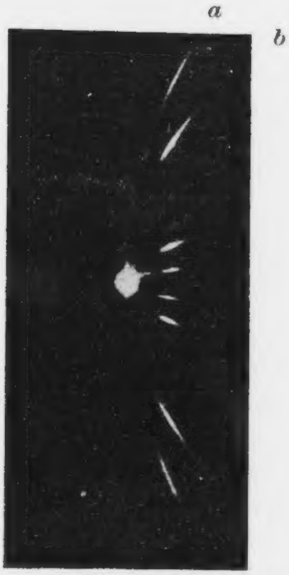


Figure 5.



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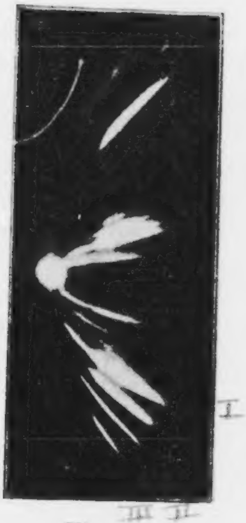

Figure 7.

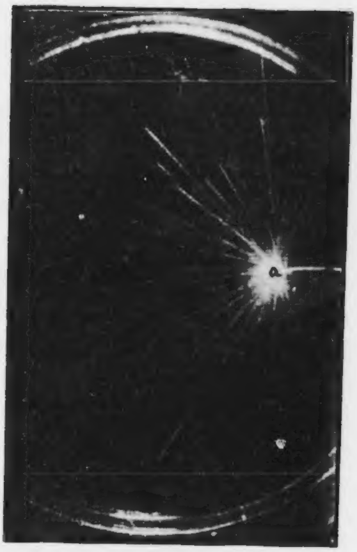

Figure 8.

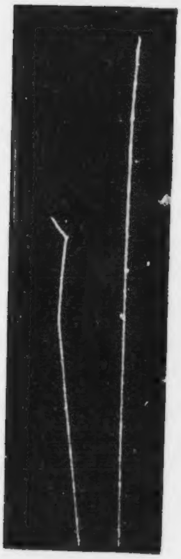

Figure 9.

Figure 10.

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mon with an atom of iron. On the contrary, it has been shown that atoms of all substances contain a common constituent, that each atom contains a definite number of a fundamental unit, the *electron*—a particle of very small mass, about one-two thousandth part of that of the lightest atom, bearing a charge of negative electricity. In any particular atom the electrons are grouped about a nucleus of small dimensions bearing a charge of positive electricity equal in amount to the total negative charge carried by the electrons, so that, under normal conditions, the atom is electrically neutral. Further, the electrons are in rapid motion, revolving about the nucleus as centre. The modern atom, therefore, may be compared not inappropriately to a miniature solar system. The positive nucleus acts as a sun about which the electrons, like planets, execute their orbital motion.

According to this modern conception, therefore, all atoms have very much in common. But the Maxwellian idea of their physical independence is not the only one which has had to go. Investigations in radioactivity have shown that we must also abandon the idea that "the formation of a molecule (or atom) is an event not belonging to the order of nature under which we live." Research in this field has shown that the atomic orbital system sketched above may become unstable and a portion of an atom be shot off. What is left behind is then no longer the same atom but an atom of a new substance. In other words the dream of the old alchemists of transmuting matter has been realized. It is true, modern transmutation is not on the gross scale nor in the manner the alchemists sought after, but it is equally true that by a process of disintegration, a portion of one substance may change into another. Occasionally in some of the heavier unstable atoms a catastrophe occurs—a portion is shot off, an atom of a new substance is left behind. In this discovery the name of Prof. Rutherford, of Manchester University, formerly of McGill University, is outstanding.

The amount of experimental evidence supporting the view of the structure of matter outlined above is almost overwhelming and can scarcely be considered in an article of this kind. Recently, however, two interesting investigations bearing on this and allied subjects have been made at the Cavendish Laboratory, Cambridge. A brief account of each of them is given below.

RAYS OF POSITIVE ELECTRICITY.

If from a cylindrical glass vessel (figure 1) provided with metallic electrodes *A* and *B* at each end, most of the air (or other gas) is exhausted, it is found on joining the electrodes to the terminals of a sufficiently powerful electric machine, that an electric current passes through the gas. A simple explanation of this phenomenon may be given. On account of the electrical pressure (potential difference) existing between the electrodes, many of the atoms lose one or more of their electrons and are consequently left with an excess of positive electricity. We have then in the vessel, in addition to ordinary neutral atoms, free negative electrons and positively charged atoms, both of which frequently attach themselves to neutral atoms or molecules, thus forming what are called negative and positive *ions*. The gas in this condition is said to be *ionized*. Now, since positive electricity attracts negative and repels its own kind, we have a stream of negative ions moving towards the positive electrode and a stream of positive ions in the opposite direction. It is this stream that constitutes the current of electricity in the vessel.

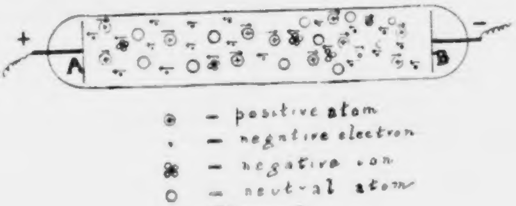

Figure 1.

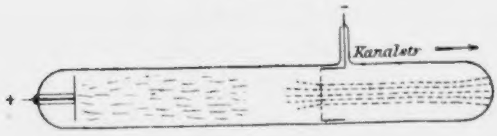

Figure 2.

If now the negative electrode perforated with several holes is placed so as to divide the vessel into two parts, as in figure 2, some of the positively charged particles moving towards this electrode will pass through the holes into what we may call the observation chamber. These particles entering the observation chamber are called *positive rays*. They were first observed in 1886 by Goldstein, a German physicist, who for obvious reasons called them *canal rays*.. Later, however, Sir J. J. Thomson, who has made an exhaustive study of some of their properties, changed their name to that of positive rays.

Prof. Thomson's investigations have been chiefly along lines which have led to the use of these rays as a means of analysing the contents of the vessel in which they are produced. The possibility of making such an analysis with any degree of accuracy was greatly helped by the property these rays have of affecting a photographic plate on which they fall. If an ordinary sensitive plate is placed *inside* the apparatus and the rays are allowed to fall on it for a very short time, on development a sharp image of the spot where the rays hit is obtained. If the rays can enter the observation chamber only through a narrow tunnel, such as shown in fig. 3, the spot obtained on a plate placed at *cd* (fig. 3) is small and circular. Suppose now that our stream of particles pass between two electrically charged plates P_1 and P_2 (figure 3) before they hit the photographic plate. On account of the charges borne by the particles they will be deflected from their original path. If each particle carries only one positive charge, or, in other words, if each has lost only one electron (and for the present we shall assume that to be the case), the deflecting force acting on each will be the same. It follows, therefore, that the lighter particles will be deflected more than the heavier, the slower more than the faster. In this way a sifting process takes place, and if, under these conditions, the stream is allowed to fall on the photographic plate, we find a narrow band (see figure 4) instead of a circular spot. The part nearer the origi-

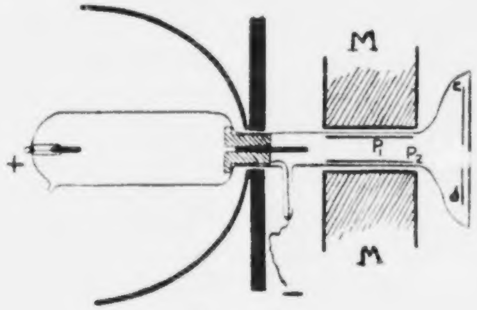

Figure 3.

nal spot is due to the action of the heavier and the faster particles, the more remote portion of the band to the lighter as well as the slower rays. Suppose, now, that in addition to the electric field, placed so as to deflect the rays horizontally, a magnet *MM* (figure 3) is placed so as to deflect the particles vertically. Then if both fields act simultaneously, the sifting or sorting process now results in the presence on the photographic plate of curved lines, *each line corresponding to a particular kind of particle.* To be more accurate, if, as we have assumed above, each particle bears one unit charge, all particles of the same mass, *no matter with what speed they move,* give rise to a parabolic curve. Further, it can be shown that the atomic weight of each kind of particle may be found directly and simply by measuring the vertical deflection of any portion of the corresponding curve. Reproductions of actual photographs obtained by Prof. Thomson are given in figures 5, 6 and 7. In figure 6 the lines marked *a* and *b* correspond respectively to the atom and the molecule of hydrogen.

We have, therefore, a new, simple and direct method of chemical analysis, the advantages of which are apparent. (1) Not only is the presence of an element indicated, as is the case in spectrum analysis, but at the same time the value of its atomic weight is given. Two good examples of the advantage of this may be given. From an analysis of the gases obtained from the residues of liquid air, Prof. Thomson found on his photographs a curve corresponding to an atomic weight 22. Now no known element has this atomic weight. Was it then a new element? In seeking an answer to this question, Prof. Thomson examined several specimens of neon, a rare gas of generally accepted atomic weight 20. In all cases a line 22 occurred on his photographs, in addition to a line 20. He has concluded, therefore, that "there can be little doubt that what has been called neon is not a simple gas but a mixture of two gases, one of which has an atomic weight about 20 and the other about 22."

Again, during the last year or two Prof. Thomson has been investigating the properties of a substance which gave rise to a photographic line corresponding to an atomic weight 3. Now, again, no known element has this atomic weight. Was this too a new element? For over a year this point has been under investigation in the Cavendish laboratory. According to the latest available information, the curve is considered to arise from a tri-atomic form of hydrogen (H_3).

(2) The method is extremely sensitive, even more so than is the case with the spectroscope. With one-hundredth of a milligram (less than one-six thousandth part of a grain) of a substance in the tube, and with an exposure of less than one-millionth of a second, not only is the corresponding curve found on the plate, but at the same time its atomic weight may be obtained with an accuracy of less than one per cent.

(3) Because of the sensitiveness of the method, substances existing in the vessel only for a very short time leave their record behind them. The importance of this is at once evident.

(4) Impurities, so bothersome in ordinary analysis, have few, if any, harmful effects. They simply give rise to additional curves on the plates.

MULTIPLE CHARGES.

We have assumed that each positively charged ray carries only one unit charge, or, in other words, that it has lost only one electron. But there is nothing in the picture of the atom given above to indicate that this should be the case. Cannot an atom sometimes lose more than one electron and thus bear two, three, four and even more charges of positive electricity? That this is actually the case has also been shown by Prof. Thomson. A careful analysis of all the lines which appear on his photographs has shown that all curves which begin at the line *AA'* (figure 5) correspond to particles which have lost only one electron, whereas the prolongation of a line extending beyond this distance (see lines marked *C, C'*, figure 5) is due to particles which have lost *more* than one electron.

To make clear why this is so, a brief consideration of one or two other points is necessary. The particles giving rise to the initial (that is, least deflected) portions of all curves are those which possess the maximum amount of energy, or in other words, those which have acquired their speed by travelling the whole length of the electric field between the electrodes of the discharge chamber. If now we assume that atoms may lose two electrons and so become doubly positively charged, the fastest of these will enter the observation chamber with just twice the amount of energy of the corresponding singly charged particles. What now will be the deflection of such doubly charged particles? When it is remembered that, although they have a double amount of energy, on account of their double charge the electric deflecting force due to the plates P_1 P_2 (figure 3) is also doubled, it will be seen there will be no change in this deflection. Whence, then, comes the prolongation of some of the curves? This is the result of what is known as *re-combination*, a phenomenon always occurring in ionized gases. Positively charged particles sometimes "pick up" a free negative electron, thus forming either a neutral body or one whose positive charge has been lessened by one unit. That this is going on in positive ray tubes is evident from the fact that there is always an *undeflected* central spot. (See figures 5, 6, 7.) This spot indicates the presence of rays originally positively charged, which have been neutralized as a result of recombination. Since then we have neutral rays, it is reasonable to suppose that we may have in the observation chamber rays which, while primarily doubly charged, have picked up an electron and possess only one unit charge. Such rays pass through the narrow tunnel with a double supply of energy, but, on account of their ultimate single charge, are subject to a deflecting force by plates P_1 and P_2, of only the normal amount. Their deflection therefore is only half the normal amount and we have a prolongation of the curve corresponding to such particles. In a similar manner the cases of particles which have lost various numbers of electrons and regained some may be worked out.

A good illustration of the evidence of multiple charges is given in figure 7. In this photograph the prolongation of line I corresponds to atoms of the element argon which originally lost three electrons, and later regained two; line III, to those which lost three and remained in this condition. The prolongation in line II is caused by atoms which ,originally minus three electrons, have picked up one electron before entering the deflecting field. It will be noticed that in this case the prolongation extends to a point two-thirds of the normal distance from the vertical.

This method of analysis, therefore, gives us information concerning the physical nature of the substances investigated. A concrete example will perhaps make clear what is meant. A vessel containing a small quantity of oxygen has been shown to contain (*a*) neutral atoms; (*b*) neutral molecules (a union of two atoms); (*c*) atoms with one positive charge; (*d*) atoms with one negative charge; (*e*) atoms with two positive charges; (*f*) molecules with one positive charge; (*g*) molecules of ozone (a union of three atoms) with one positive charge; and (*h*) a group of six atoms (O_6) with one positive charge.

As a final illustration of the use which can be made of these positive ray photographs, the following table, giving the complete analysis of all the substances corresponding to the curves shown in figure 5, is appended:

POSITIVE.

Atomic Weight	*Substance*	*Charge*
1	Hydrogen atom	+1
1.99	Hydrogen molecule	+1
6.80	Nitrogen atom	+2
11.40	Carbon atom	+1
13.95	Nitrogen atom	+1
28.1	Nitrogen molecule	+1
39	Argon atom	+1
100	Mercury atom	+2
198	Mercury atom	+1

NEGATIVE.

1	Hydrogen atom	—1
11.2	Carbon atom	—1
15.2	Oxygen atom	—1

IONS MADE VISIBLE.

The presence of ions has been demonstrated by recent experiments performed by Mr. C. T. R. Wilson, of the Cavendish Laboratory. Ions, it must be remembered, are much too small to be seen even with the aid of the best ultramicroscope. By making each ion become the centre of a small drop of water, however, Mr. Wilson has succeeded in visualizing their existence, and photographing the appearance of an ionized gas under various conditions. The method employed is based on the principle that when air (or other gas) suddenly expands to fill a larger volume it becomes cooled. If before the expansion the gas has been saturated with water vapor, after the expansion, on account of the cooling there is more than enough vapor to saturate the gas and some of it condenses out. If any particles of dust are present, condensation takes place readily on these as nuclei—a fact familiar to all who have noted the heavy fogs in smoky atmospheres. Should no such dust particles be present, however, under proper conditions, *ions* act as nuclei for condensation. In this way, when the gas expands, if any ions are present, a small *visible* water drop forms around the *invisible* ion. By illuminating the gas immediately after expansion, and by taking an instantaneous photograph, pictures of the arrangements of ions as caused by different agencies have been obtained by Mr. Wilson.

This method has been used to visualize some of the facts of radioactivity. When an atom disintegrates in the manner noted above, the transformation is frequently accompanied by the emission of a rapidly moving electron (in this case generally called a β particle) and by a much heavier but more slowly moving positively charged α particle. (Incidentally it may be noted that the α particle has been identified with an atom of the rare gas, helium.) Now when a quickly moving charged particle moves through a gas it continually encounters ordinary neutral atoms, *from some of which it succeeds in extracting an electron.* In other words, as an α or β particle moves along, it ionizes the gas along its path. This has been shown in a beautiful manner by Mr. Wilson. By placing a small quantity of a radioactive substance within his expansion apparatus, he obtained photographs which show the actual paths of α and β particles by the trail of ions left behind them. In the case of an α particle, so many ions are produced that a continuous line is seen on the photographs. In figure 8 the radial lines represent the paths of numerous α particles shot off from the radioactive substance placed at *a*, while figure 9 shows a photograph of the trails of two single α particles. In the case of the lighter β particle, a much smaller number of ions are made and a discontinuous line is obtained. This is well shown in figure 10, a reproduction of a photograph of the trail of a single β particle. In this latter case it will be seen that the individual ions may be counted. Readers interested in modern physics will find a brief but attractive presentation of recent developments along lines discussed in this paper in a small book, "Beyond the Atom," by Prof. Cox.*

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* "Beyond the Atom," Cox. Cambridge Univ. Press, 1913. 1s. net.

J. K. ROBERTSON.